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A SLOW STRAIN-RATE TENSILE TESTING MACHINE

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M.R. Kindermann
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Aircraft Materials Technical Memorandum 399

A SLOW STRAIN-RATE TENSILE TESTING MACHINE

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SUMMARY

A slow strain-rate tensile testing machine intended for use in investigations into adhesive-bond durability and hydrogen embrittlement in metals is described. It is of a basically simple design to facilitate ease of manufacture and its stepping-motor drive permits electronic control of the straining rate over a range of several orders of magnitude. The driving circuitry provides a high degree of stability in the straining rate over extended periods and the entire system may be adapted to computer control if desired.

DSTO ARL MELBOURNE

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1. INTRODUCTION

A slow strain-rate tensile testing machine was required for the determination of the strength and durability of adhesively-bonded joints in metal specimens and for the investigation of hydrogen-embrittlement in metal alloy systems.

The variety of intended applications required a machine which could be readily modified. A modular design approach was chosen and design criteria included ease of manufacture in an average machine shop using simple manufacturing processes. The design uses commercially available materials and machine components to further simplify manufacture and reduce cost.

2. SPECIFICATIONS

The machine was required to apply a tensile load to small specimens at a predetermined and constant slow extension rate. It has been designed to apply a maximum tensile load of 20 kilonewton to the specimen over a range of extension rates between 10^{-2} nanometers per second and 10^{-2} millimeters per second.

3. MACHINE CONFIGURATION

The machine configuration is shown in the general assembly diagram (Fig. 1) where the machine frame comprises two circular section columns (1) to which two crossheads (2) are clamped. These crossheads can be moved to any desired position on the columns to accommodate a range of specimen sizes and loading linkages. The resultant tensile forces are reacted at the centre of the span of each crosshead. The tensile-load and extension rate applied to the specimen are produced by a recirculating ball screw driven at constant angular velocity and acting through a nut (3). This screw in turn is driven by a stepping motor (5) through two reduction gearboxes (6) and a coupling of the dog clutch variety (7) permitting mechanical isolation of the drive from the ball screw for setting up experiments. The screw, nut, gearboxes and stepping motor have a common axis, which is coincident with the line of action of the tensile load applied to the specimen and the axis of symmetry of the machine. The screw used was a commercial ball-screw assembly of suitable dimensions and load capacity with the reduction gearboxes being functionally similar to epicyclic gearboxes of coaxial configuration. These gearboxes, manufactured by Sumitomo of Japan and sold under the trade-name of 'Cyclodrive' have their rotational direction between input and output reversed. Gearboxes with alternative reduction ratios are readily interchanged since they are mounted on removable crossheads clamped to the columns.

4. MATERIALS USED IN CONSTRUCTION

1. Columns

The columns form part of the loading-frame and were fabricated from commercial hard chromium-plated precision steel bar. Other commercially available precision finished bar may be used, but should be plated to inhibit corrosion in a corrosive environment.

2. Crossheads and Mounting Plates for Motor and Gearboxes

The crossheads and mounting plates (removable crossheads) were all machined from 6063-T5 aluminium alloy which is of low density and relatively easy to machine to size. Other materials such as cast alloys could be used if desired, or alternatively the crossheads may be fabricated from rolled sections by welding. The crossheads were designed to provide a deflection at their centres of less then 10 micrometres under the maximum design load of 20 kilonewton.

3(a) Ram Housing and Ram

The ram housing was made from aluminium alloy while the ram was made from free-machining stainless steel. Materials selected for the ram housing and ram must be satisfactory in a sliding application without galling as the ram housing provides a sliding bearing surface for the ram. The material chosen for the ram should have a high resistance to corrosion without the need for plating.

3(b) Bearing Housing and Cap

The bearing housing and cap were made from carbon steel bar, but other metals could be used as cast, rolled, or drawn.

3(c) Handwheel and Coupling

The handwheel and coupling were made from stainless steel since the material used must be tough and have a high resistance to wear and corrosion. The coupling itself was a modified 'Oldham' type coupling with the spider replaced by a tungsten carbide cutting tool insert 19 millimetres square and 5 millimetres thick. Those used in the A.R.L. machines were worn inserts discarded from the machine shop.

3(d) Rotary Couplings

Rotary couplings used to couple gearboxes and motor to gearbox were commercially available types permitting small angular and axial misalignments between shafts to which they are fitted.

3(e) Surface Finishes

Non-mating surfaces were painted to inhibit corrosion. Where non-rubbing mating surfaces exist, these were generally protected against corrosion by zinc plating, with chromium or nickel plating being applied to mating surfaces where rubbing or wearing occurs.

5. STEPPING MOTOR DRIVE

The stepping motor drive circuitry generates a sequence of discrete pulses with their repetition rate controlled to a high degree of precision. A continuously variable pulse-rate was also provided for convenience in setting up specimens prior to running a test.

The discrete pulse sequence is derived from a 1.8 MHz quartz crystal oscillator forming part of a bit-rate generator within an integrated circuit (Motorola type MC14411). This bit-rate generator produces outputs at various bit-rates which are taken to two multiple slide switches permitting any one bit-rate to be selected. The selected bit-rate signal becomes the input to two synchronous 4-bit binary counters that together enable the input pulse-rate to be divided by a selectable integral ratio between 1 and 255:1. This signal is made the input to a decade frequency divider chain of seven type LS90 counters permitting decade division of the pulse-rate by a maximum of 10^7; the division ratio being selected by means of a panel mounted rotary switch. The signal from the decade divider is next passed to a binary-coded-decimal (BCD) counter to permit further division of the pulse-rate by selectable integers in the range 1-9, this counter being under the control of a panel-mounted thumbwheel switch. This BCD counter has two

series-connected Schmitt-trigger inverters each having a 1.5 volt positive-going threshold requirement inserted between the 'borrow' and 'load' terminals to improve noise immunity and thus prevent irregular operation of the stepping motor. The output pulse from this counter is passed to a monostable multivibrator to increase the pulse length to 600 nanoseconds. Finally, the signal is passed to an 'AND' gate to provide a means of externally switching the control pulse to the stepping-motor control board.

The stepping motor control board accepts the pulse sequence from the pulse generator circuitry and converts it to a four-phase step-wise signal which, after power amplification, is used to drive the stepping-motor. The rotational sequence of phases is reversible in order that the stepping motor may be driven in either direction.

The output signal from the decade divider is also passed to two series-connected BCD counters operating in the count down mode to provide a further reduction in the pulse rate by selectable integral ratios between 1 and 99:1 ; the ratio being selected by another panel-mounted thumbwheel switch. The output from this latter stage is intended to be used for triggering external circuitry, as for example in triggering digital data logging equipment. This trigger signal has also had its pulse width increased to 600 nanoseconds by a monostable multivibrator to provide reliable triggering of external circuits.

The continuously variable pulse-rate signal is derived from a phase-shift oscillator of the resistance-capacitance type, with the resistance forming the variable frequency determining element. Finally, a terminal is provided on the stepping-motor control board to permit computer control of the stepping motor if such is required.

6. DISCUSSION

As this machine was designed to fulfil requirements for a variety of experiments, the frame and loading mechanism were designed to provide an exceptionally rigid assembly. Rigidity is also of paramount importance where long-term experiments are conducted at extremely low displacement rates. Machine softness calculations were performed for the crossheads and columns. These calculations revealed that the central deflection of the crossheads under 20 kilonewton loading is 6.5 micrometres. Thus the total softness in the machine due to crosshead bending is approximately 13 micrometres at full load. Softness due to compression in the columns is in direct proportion to the crosshead separation. The compression of two 38 millimetre diameter steel columns of typical length 0.5 metre under a total force of 20 kilonewton is 22.4 micrometres. Softness due to buckling of the columns is considered negligible. Neglecting deformation in the loading mechanism, the total machine softness under full load is estimated to be approximately 50 micrometres. Machine softness is therefore significant for tests designed to measure the mechanical properties of metal specimens, but is negligible for fracture experiments conducted on adhesively bonded double cantilever beam specimens.

The choice of loading frame component materials was made on the basis of cost and availability. However, materials chosen for these components should be ductile, malleable, and free from residual stresses so as to be dimensionally stable during use. The ball-screw and nut should operate smoothly under load and therefore a ground screw thread is preferable to a rolled thread. The ball bearing supporting the reactive load of the ball screw was initially a double row angular contact type, but this was found to distort badly under heavy axial load. A double-acting ball thrust bearing was substituted which was found satisfactory and did not introduce significant additional softness in the machine. Concealed socket headed high-tensile cap screws were used in the assembly both for aesthetic reasons and to assist in producing a compact design. Hexagonal headed high-tensile bolts could be substituted in some places if desired, provided space is allowed to accommodate the bolt-heads. It is important to allow for plating thickness

where close tolerances apply to mating components. Also, closely mated components should not have their contacting surfaces plated with identical metals as this could lead to seizure problems where high clamping forces are involved. Component surfaces subject to frequent handling should be protected by painting or plating.

The stepping motor control and driving circuitry is comparatively simple, being completely self-contained and independent of external control. However, if desired, computer control can be achieved through two control lines. One control line must provide a sequence of pulses with a period in the range 10 milliseconds to 10^5 seconds. The second control line must provide TTL levels to control the clockwise or anti-clockwise rotation of the stepping motor.

The operation of the driving circuitry was troublesome initially in that spurious triggering occurred in the stepping-motor driving circuitry. This appeared to be caused by a combination of factors, viz. earthing, component placement and mounting, overheating of power transistors in the final driving circuit and pickup of digital noise. Much of the problem was overcome by providing pulse-stretching multivibrators and Schmitt triggers in those parts of the circuit where noise immunity needed improvement. Layout of the circuit is generally considered to be non-critical. However, the final drive circuitry generated fast rise-time, high current pulses which cause high amplitude damped oscillations to occur when fed to the essentially inductive load provided by the stepping motor. These pulses may be inductively or capacitively coupled inadvertently to the pulse-generation circuitry if care is not taken in the layout design to avoid such a situation occurring.

7. CONCLUSION

Two of these machines constructed in this laboratory are presently being used for environmental durability testing of adhesive-bond specimens. These machines have provided satisfactory service in this application for extended periods of up to several weeks without any operational difficulties.

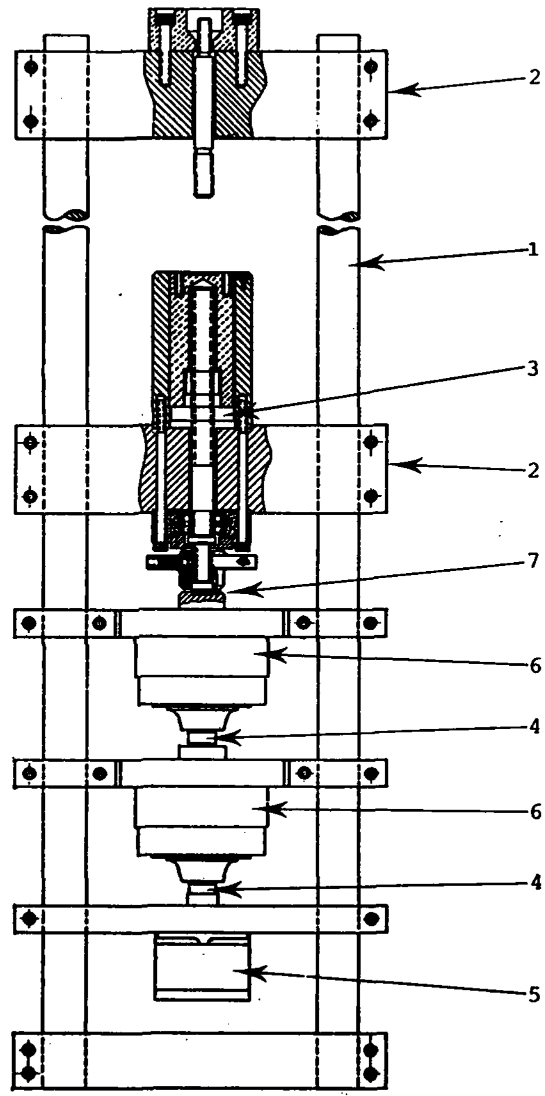
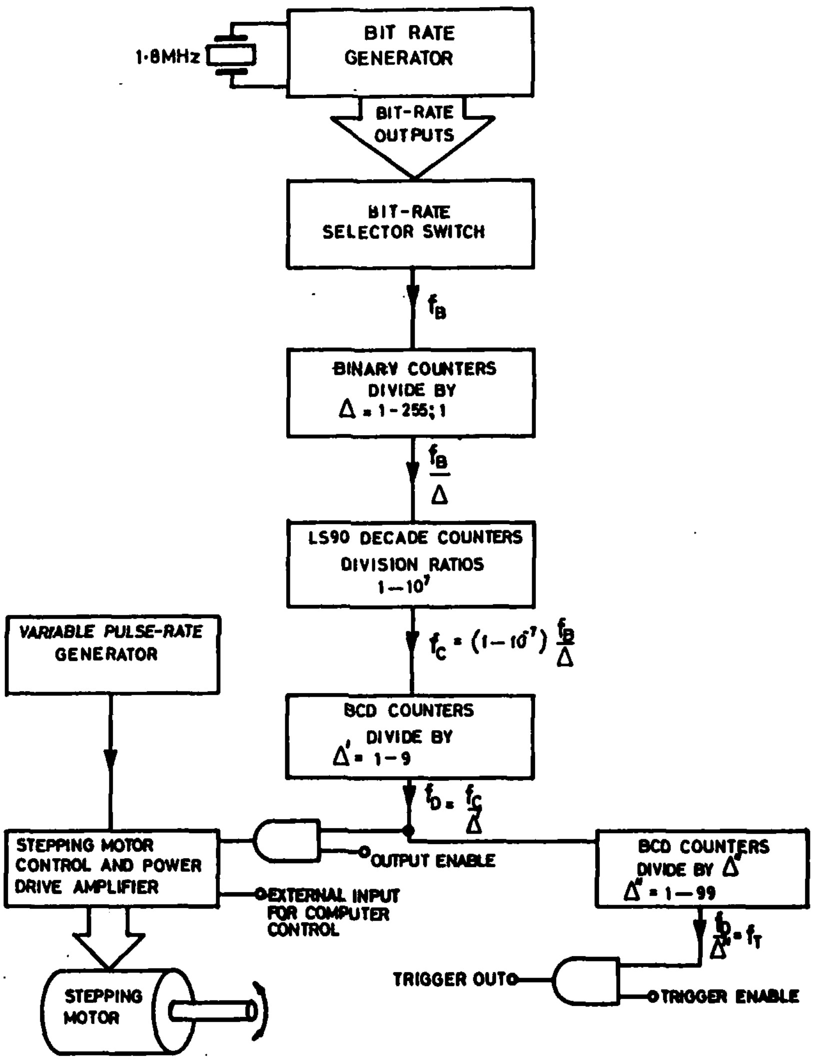


Figure 1



1·8MHz
BIT RATE GENERATOR
BIT-RATE OUTPUTS
BIT-RATE SELECTOR SWITCH
f_B
BINARY COUNTERS DIVIDE BY Δ = 1-255; 1
$\frac{f_B}{\Delta}$
LS90 DECADE COUNTERS DIVISION RATIOS 1—10^7
$f_C = (1-10^7)\frac{f_B}{\Delta}$
VARIABLE PULSE-RATE GENERATOR
BCD COUNTERS DIVIDE BY $\Delta' = 1-9$
$f_D = \frac{f_C}{\Delta'}$
STEPPING MOTOR CONTROL AND POWER DRIVE AMPLIFIER
OUTPUT ENABLE
EXTERNAL INPUT FOR COMPUTER CONTROL
BCD COUNTERS DIVIDE BY Δ''
$\Delta'' = 1-99$
$\frac{f_D}{\Delta''} = f_T$
STEPPING MOTOR
TRIGGER OUT
TRIGGER ENABLE

Figure 2

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